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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

NATIONAL RESEARCH ON THE QUESTION OF SPACE DEBRIS

Note by the Secretariat

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1. In paragraph 24 of resolution 46/45 of 9 December 1991, the General Assembly considered that it was essential that Member States pay more attention to the problem of collisions with space debris and other aspects of space debris, and called for the continuation of national research on this question, for the development of improved technology for the monitoring of space debris and for the compilation and dissemination of data on space debris. To the extent possible, the Assembly noted, information thereon should be provided to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in order to allow it to follow this area more closely.

2. The General Assembly, in paragraph 25 of the same resolution, requested the Secretary-General to invite Member States to provide information on their national research on space debris to the Subcommittee.

3. The Secretary-General addressed a note verbale dated 11 December 1991 to all Member States, inviting them to communicate to the Secretariat, by 31 January 1992, the information requested above so that the Secretariat could prepare a report containing this information for submission to the Subcommittee at its twenty-ninth session.

4. The present document was prepared by the Secretariat on the basis of information received from Member States as of 5 February 1992. Information received subsequent to that date will be included in addenda to the present document.

AUSTRALIA

[Original: English]

AUSTRALIAN RESEARCH ON SPACE DEBRIS

Introduction

National research on space debris in Australia is carried out in two distinct fronts, first, through two commercial companies, Spaceguard Pty. Ltd. and SODA Pty. Ltd., and secondly, through the University of Adelaide. Both areas receive funding from the Australian Government.

Current Australian research activities in the space debris field are as follows.

1. Impact modelling

The probabilities, impact angles and velocities upon different faces of a satellite by space debris may be calculated using a suite of programs developed by Spaceguard Pty. Ltd./SODA Pty. Ltd. These programs make use of the input satellite orbit, orientation and facial areas, the known (tracked by

US SPACECOM) space debris population (sizes over 10 cm), and state-of-the-art models of the distribution of smaller debris (sizes below 10 cm) based upon all known fragmentation events.

The results of such calculations allow the damage potential for each face of a satellite to be determined: for example, the perforation rate through a satellite skin, or the shielding required. These results are of use in a variety of situations, such as:

- Satellite engineering design;
- Shielding design by buffers around larger structures such as the planned Space Station;
- Insurance premium assessments considering the risk posed to commercial satellites;
- Laboratory studies of impacts.

This work into space debris is being financed through a number of Government agencies, including grants under the Australian Government's industrial research and development scheme.

Spaceguard Pty. Ltd. and SODA Software Pty. Ltd. were set up in order to service a perceived market concerned with the international satellite insurance industry. These companies are dedicated to providing hazard assessments for satellites under the threat of impacts by man-made debris and natural meteoroids. Spaceguard is able to provide a hazard assessment for specific satellites (i.e., the computations take into account its orbit, size, orientation and so on).

2. Analysis of returned spacecraft samples

In January 1990, the Long Duration Exposure Facility was returned to Earth with the Space Shuttle after five years in orbit. One of the most important space debris-meteoroid impact experiments on board was the set of exposure plates designed and operated by the teams at the Unit for Space Sciences of the University of Kent.

Spaceguard Pty. Ltd. and the Anglo-Australian Observatory are involved in the analysis of these data. Australian involvement stems from software developed which allows the calculation of the impact probability, velocity and trajectory upon each face for objectives in stipulated geocentric orbits (i.e., space debris). This project is receiving funding from the Australian Research Council and the British Science and Engineering Research Council.

3. Radar observations of small infalling debris

The hazard posed by debris is dominated by the particles in the 1 mm-1 cm range, and there are currently no available techniques for detecting such debris in space.

One way of determining the flux of such articles, and getting some idea of their orbital properties, may be to detect them as they re-enter the Earth's atmosphere, forming artificial meteors. Radars operating in the HF-VHF bands have been used for many years to detect natural meteors, these being predominantly in the size range straddling 1 mm. Such meteor radars have been operated by the University of Adelaide for four decades. Building upon this expertise, a programme has begun to investigate the feasibility of detecting space debris in this way.

After this exploratory stage it is intended that the Jindalee over-the-horizon radar in central Australia be used; this is the most powerful detector of meteors ever operated, and initial studies show that it may be ideally suited for debris studies due to its antenna patterns.

4. International collaboration on space debris

Australia is represented on a Japanese committee on space debris. This group involves a variety of scientists and engineers from government organizations and industry, and is to consider a Japanese national response to the growing debris problem, particularly with respect to their involvement in the Space Station.

CHILE

[Original: Spanish]

The Committee for Space Affairs of Chile has examined fragments of space debris, presumably originating from the Soviet orbital station Salyut 7. The debris was discovered on 7 February 1991, in southern Chile, about 13 kilometres west of the city of Puerto Varas. Attached is a report prepared by the Committee for Space Affairs concerning the analysis of the remains of the orbital station Salyut 7.

Annex

REPORT ON SPACE DEBRIS FOUND IN SOUTHERN CHILE

(7 February 1991)

I. BACKGROUND

A. On 7 February 1991, at approximately 0200 hours local time, something resembling a shooting star was seen traversing the sky from west to east in the vicinity of Nueva Braunau, in the Tenth Region of the national territory. Subsequently, at approximately 1500 hours on 7 February, a local farmer found a cylindrical metal object, which was removed by carabineros from Puerto Varas and delivered to the Air Force for analysis and evaluation.

B. The Air Force, through its Third Air Brigade based in Puerto Montt, is recovering the remains of the debris and sending them to the Committee for Space Affairs.

II. DETAILS ON THE LOCATION AND IDENTIFICATION OF THE RECOVERED DEBRIS

A. Location

1. Location of the fallen debris. The space debris was seen by residents of the area on 7 February 1991 at approximately 0200 hours, traversing the sky from west to east and resembling a shooting star.

2. On 7 February 1991, on a farm in Nueva Braunau, at approximately 1500 hours, while baling fodder for livestock, farmers found an unfamiliar cylindrical metal object. The site of the discovery is approximately 13 kilometres west of Puerto Varas and 500 metres south of the road linking Nueva Braunau with Puerto Varas and perpendicular to the longitudinal southern highway (Route 55), with the coordinates 41°19' south, 73°05' west (see appendix). According to eyewitnesses (although neither they nor anyone else observed the impact), before impact the debris described a trajectory from west to east.

3. Identification of the site of the impact. The area of impact of the cylindrical artefact was a field used to produce fodder for livestock. At the site of the impact, the debris did not cause any apparent damage; no traces of the impact or fall of the artefact were detected, nor did it leave any visible marks.

B. Identification of the object

1. Preliminary technical inspection

Before the aforementioned object was taken to the laboratory, visual technical inspection tests were conducted in order to rule out possible radioactive contamination. The following tests were carried out:

(a) Measurement with a telescopic sensor using a 4 (M) Teledetector 61 12D. Results: 0.10 MR/h (background radiation level);

(b) Measurement with a Szintomat scintillation counter 6134. Results: 0.010 MR/h (background radiation level);

(c) Measurement with Berthold contamination detector. Results: negative (no contamination);

(d) The object was measured and weighed, with the following results: length of cylinder, 2.80 m; diameter, 0.46 m; thickness, 3 mils; weight, 6 kg;

(e) Detailed visual inspection revealed that the material (cylinder) had resisted considerable temperatures. Photographic set of different views of the object.

2. Laboratory

(a) Spectrometric analysis

As a result of a spectrometric test using Berpro and Radam analysers, the presence of radioactive elements in the object's original composition or of contamination resulting from its operation or trajectory was completely ruled out.

(b) X-ray fluorescence analysis

An X-ray fluorescence analysis yielded the following data on the composition of the object:

Titanium (Ti)	Normal to abundant concentration
Chromium (Cr)	Abundant concentration
Iron (Fe)	Abundant concentration
Nickel (Ni)	Normal to abundant concentration
Niobium (Nb)	Probable presence in small concentrations
Manganese (Mn)	Probable presence in small concentrations
Molybdenum (Mo)	Normal to abundant concentration

(c) Activation analysis

Laboratory analysis yielded the following data:

Major elements	Concentration (%)	Absolute standard deviation
Iron (Fe)	68.7	3.4
Chromium (Cr)	15.6	0.78
Nickel (Ni)	9.2	2.8
Manganese (Mn)	1.03	0.03

Minor elements	Concentration (Parts per million)	Absolute standard deviation
Cobalt (Co)	949	47
Molybdenum (Mo)	860	66
Tungsten (W)	508	25
Antimony (Sb)	44	10
Arsenic (As)	3.4	0.2
Zinc (Zn)	200	

Note: In this laboratory, because of the high concentration of chromium, it was not possible to determine the concentration of titanium.

3. Laboratory results indicate that the component materials are used in the aerospace industry and that the object found was a product of advanced technology, thereby confirming that it is a piece of space debris.

C. Other information

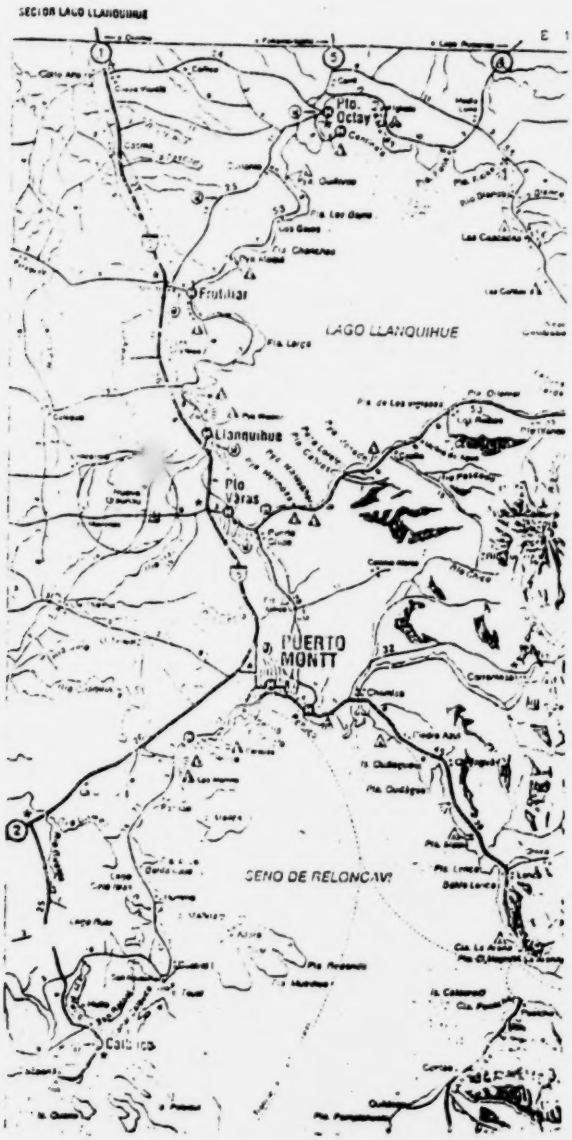
After nine years in orbit, the abandoned Soviet space station Salyut-7 re-entered the Earth's atmosphere on 6 October 1991 at 1044 hours Eastern Time.

That space vehicle was launched in 1982 and used by cosmonauts until 1986; it had a length of 90 feet and a weight of 43 tons; its orbital speed was 17,000 mi/hr.

Its re-entry into the atmosphere left a luminous trail in a north-easterly direction, crossing the skies of southern Chile and Argentina, where the object presumably fell.

Appendix

GEOGRAPHICAL INFORMATION REGARDING THE SITE OF DISCOVERY OF THE SPACE DEBRIS



CUBA

[Original: Spanish]

The Academy of Sciences of Cuba declares that Cuba is not engaged in space research and does not produce space debris.

FIJI

[Original: English]

The Government of the Republic of Fiji has not conducted national research on space debris.

JAPAN

[Original: English]

The following working papers on space debris were written by the specialists who play a major role in the scientific studies on this matter. The future policy of the Government of Japan will not be restricted by these papers.

The Government of Japan hopes that these working papers will contribute to further examination of this question.

Annex I

STUDY OF SPACE-BASED MEASUREMENT AND COLLISION PREDICTION

1. Introduction

Measurement of space debris is one of the most fundamental tasks in the space debris problems. This area seems to be one in which the National Space Development Agency (NASDA) can play an effective role towards better understanding and solution of the problem. Space-based measurement, i.e. measurement by a sensor on board a spacecraft, will help avoid collision of debris to the same spacecraft and also complement and extend ground-based debris data.

NASDA took up feasibility studies on orbit determination and collision warning by use of space-based measurement. Orbit determination improves debris data catalogues and also makes possible collision prediction, but collision prediction may not rely on orbit determination. In the present paper, discussion is limited to a method of collision warning that does not require orbit determination.

2. Collision prediction analysis

(1) Characteristics of relative velocity

Direction and magnitude of a debris object relative to a spacecraft was studied to define requirements of attitude and ranging of debris sensors. The study was performed under spacecraft conditions of altitude-500 km, assuming the Space Station. Range of debris orbits calculated is: eccentricity, 0-0.2, perigee altitude, 300-500 km and relative orbital inclination, 0-369 deg.

Figure 1 shows speed versus azimuth angle of debris at the instant of collision as seen from the spacecraft. It is seen that when the azimuth is over +/- 90 deg, i.e. debris is approaching from between the side and behind, relative speed is smaller than 3 km/s. For likely cases, which has azimuth within +/- 30 to 90 deg, collision velocity ranges from 2 to 14 km/s, and is 8 km/s in average.

Figure 2 shows elevation versus azimuth of debris at the instant of collision, as seen from the spacecraft. When the azimuth is within +/- 90 deg, the elevation falls within +/- 10 deg, which means very close to the local plane. If JEM is considered, the elevation extends over +/- 10 to 40 deg, since it is located at the rear of the Space Station. This must be taken into account in sensor requirements considerations.

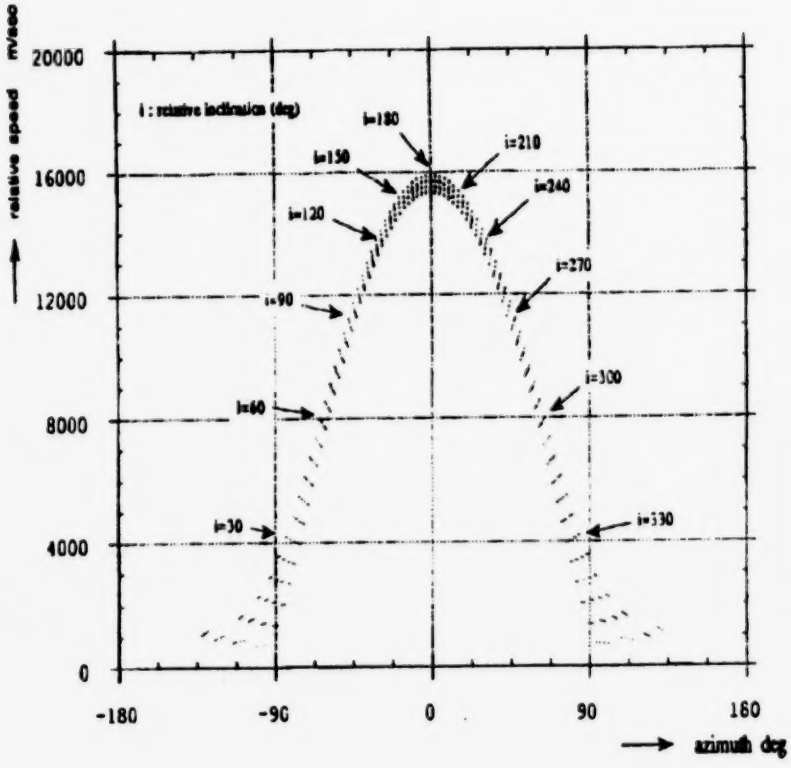


Fig. 1 Relative speed and direction of debris at collision

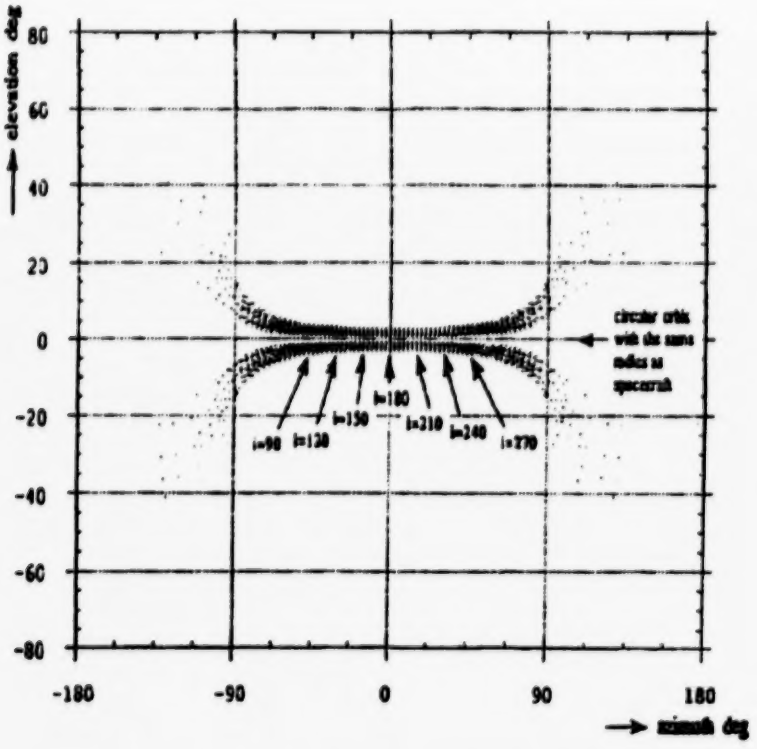


Fig. 2 Direction of debris at collision as seen from spacecraft

(2) Characteristics of debris trajectory

For the in situ (or immediate detection mode) collision prediction, it is necessary to observe debris trajectories from the spacecraft. Assuming the spacecraft to be that with 300 km altitude, trajectories were analysed for debris orbital elements extending sufficiently widely as follows:

a: semi-major axis: 6378+ (300-20500) km

e: eccentricity: 0 - about 0.75

i: relative inclination: 0 - 120 deg

Figure 3 shows a debris trajectory projected on the local plane of the spacecraft, with the point of collision at the point XL=0 and YL=0. Figure 4 shows the relation between azimuth and elevation angles and the range (distance) for the same object as in figure 3. Similarly, figure 5 and figure 6 show the trajectory and angles with regard to distance, respectively, for an object with another orbit. The first case represents a common LEO debris orbit, and the second can roughly represent the Molniya type orbit.

It may be seen from these results that the debris azimuth is either virtually constant, or its change rate is constant if there is any noticeable change, all the way from the detectable limit until collision.

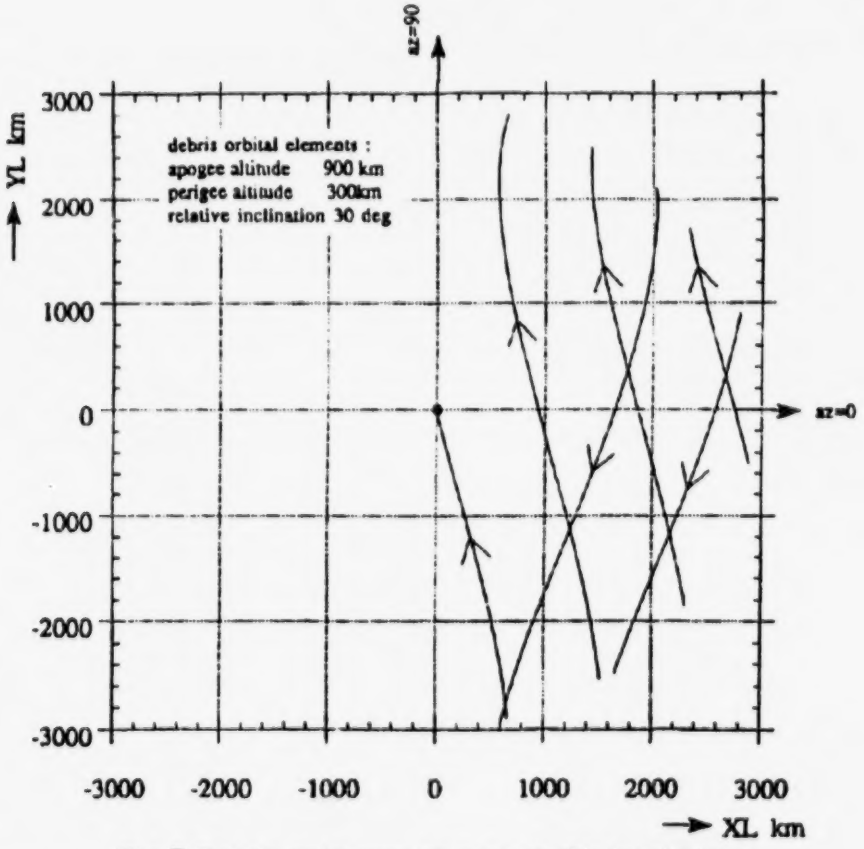


Fig.3 Debris trajectory on spacecraft's local plane

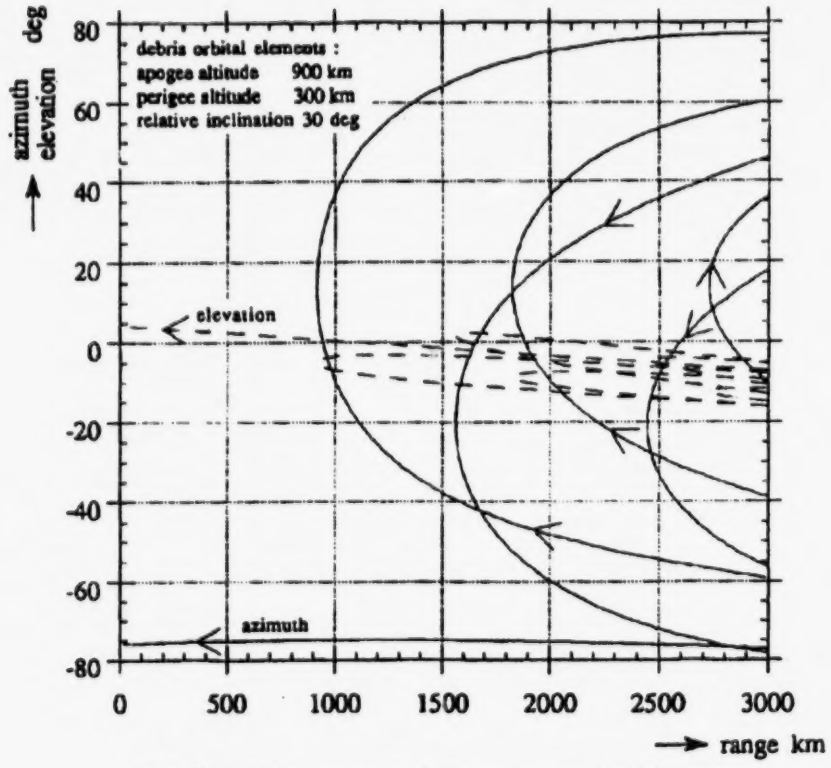


Fig.4 Debris range and direction angle history

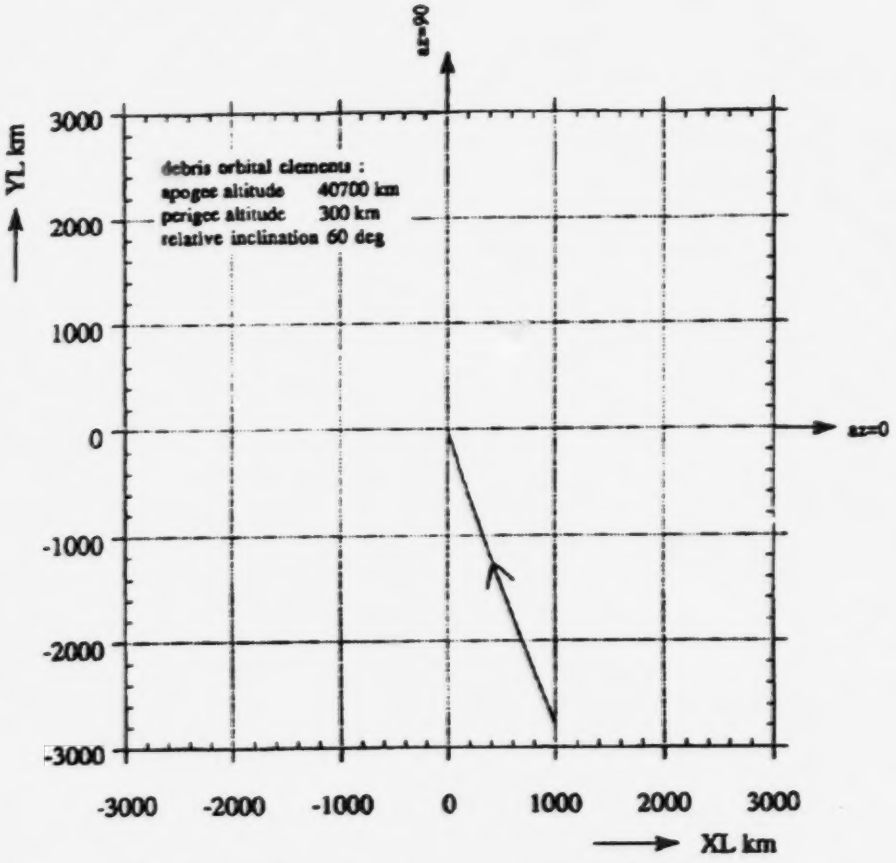


Fig.5 Debris trajectory on spacecraft's local plane

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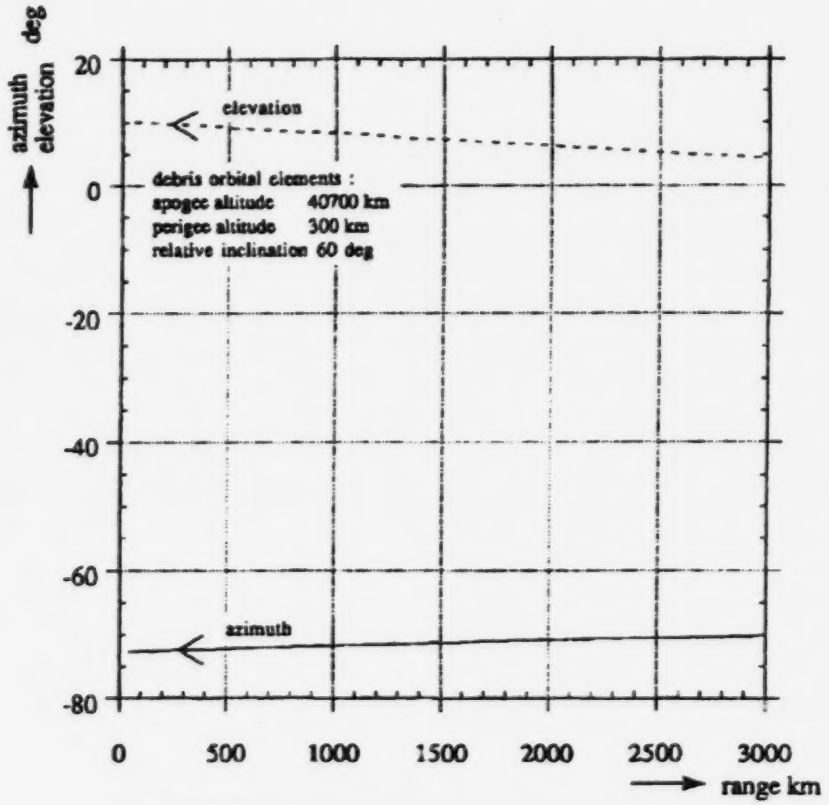


Fig.6 Debris range and direction angle history

3. Conclusions

1. LEO debris can be observed for a few times before collision.

2. Once an object is detected, collision warning is possible by only watching the change of its azimuth, and it is not necessary to fully determine its orbit.

3. Collision is to take place in a few minutes if the azimuth is virtually constant or changing at a constant rate.

NASDA will perform further studies to define collision warning/non-warning criteria that are valid for most possible cases.

Annex II

A BRIEF OVERVIEW OF SPACE DEBRIS STUDIES

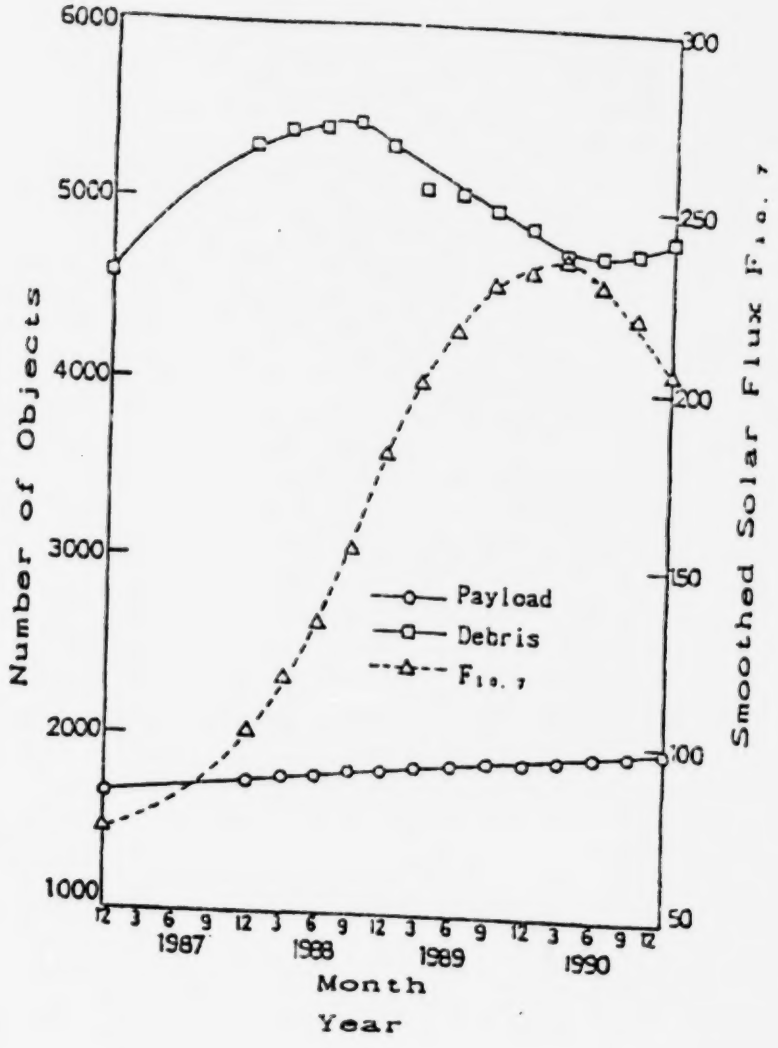
1. General survey and investigation of the space debris problem

As a design environment of large space structures, the space debris problem has been surveyed and studied in the field of observation, cause, modelling and protection.

1. The NASA Satellite Situation Report has been surveyed in order to understand the space debris environment. As an example, the trackable payloads and debris are plotted in figure 1 along with solar F10.7 radio flux. The payloads are seen to be increasing at a constant rate. On the other hand, the rate of growth of debris is seen to be decreasing with the increase of solar activity, because during solar maximum the atmosphere is heated and the atmospheric density at high altitudes increases. Thus debris population is noticeably affected by the 11-year solar cycle.

2. The modelling of collision and explosion phenomena has been investigated. The breakups of rocket upper stages and satellites are simulated by a fragmentation model in which a square plate is randomly sliced into N x N pieces. A log-normal distribution is proved applicable in case of explosion-induced fragmentation, as shown in figure 2.

3. In relation to the design of the Japanese Experimental Module (JEM), the research outputs obtained in the Apollo/Skylab era have been reappraised and various design formulas have been investigated with a combined effort with NASDA. One example is shown in figure 3, in which the effectiveness of aluminium shielding is experimentally studied. Optimum design procedures and fracture control studies are being planned by accumulating extensive experimental data.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Number of Objects
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1988
1989
1990
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Year

Fig.1

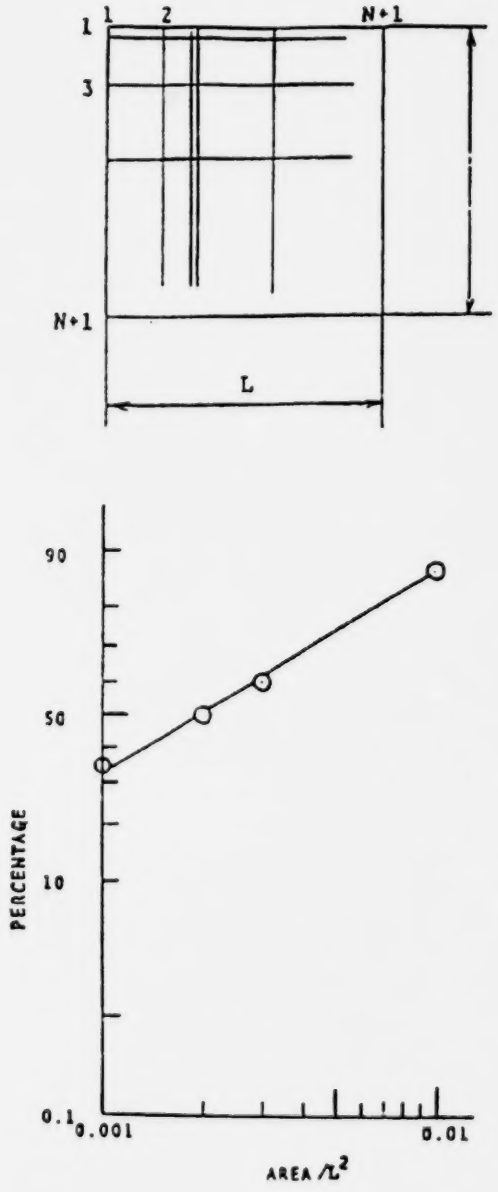
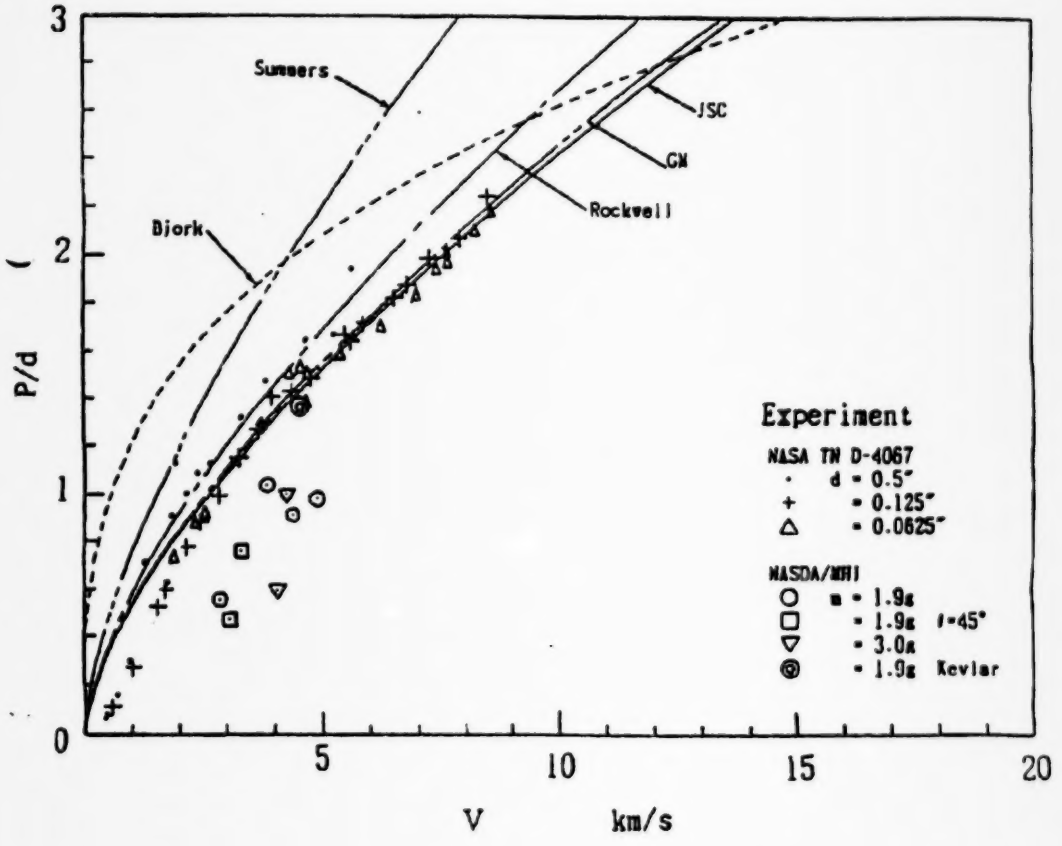


Fig.2


3
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JSC
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Rockwell
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Experiment
NASA TN D-4067
d = 0.5"
= 0.125"
= 0.0625"
NASDA/MHI
m = 1.9g
= 1.9g θ=45°
= 3.0g
= 1.9g Kevlar

Fig.3

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2. Study of hypervelocity impact phenomena and shielding designs

1. For the hypervelocity impact tests, specimens which consist of an aluminium alloy or a carbon fibre reinforced plastic (CFRP) shield and an Al alloy backup sheet are now being fabricated. The range of impact velocity is planned to be 2-7.5 km/sec.

2. The algorithms of hydrocodes are being investigated.

Annex III

OPTICAL OBSERVATION OF GEOSTATIONARY ORBITING OBJECTS USING A 1.5-METRE TELESCOPE SYSTEM WITH LOW-NOISE CCD CAMERA

1. Preface

A geostationary orbit is one of the most valuable orbits for satellite telecommunications and Earth observations. The probability of collision between satellites located in the same orbit or between geostationary orbiting debris and a satellite in a transfer orbit has been considered to be negligibly small. However, in the near future, the possibility will increase as the satellite population grows. Therefore, a technological development of monitoring geostationary orbiting objects is important.

An optical ground facility named Space Optical Communication Research Centre has been constructed in order to develop the future technologies for optical communications. This centre will be used as a fixed ground station for space optical communication experiments using a geostationary satellite (ETS-VI). The precise tracking of the geostationary satellite is one of the most important technologies to be performed in the space laser communication experiment. In this station, a 1.5-metre diameter Cassegrain type telescope is constructed to receive the laser beam from the ETS-VI. The station also has a low-noise CCD camera and an image data-processing computer. Major specifications of the telescope and performance of the CCD camera are shown in tables 1 and 2, respectively.

The present report shows some preliminary results of optical tracking of geostationary satellites by using the 1.5-m telescope with the CCD imaging system.

Table 1 Major Specifications of the Telescope

Main Telescope	
Primary Mirror Aperture:	1.5 m
Focal Length:	2.25 m
System Focal length:	infinity for Coude focus 18 m for other focuses
Mount and Control	
Structure:	Az/El Gimbal mount.
Az-El Perpendiculacy:	0.1 arc-sec.
Encoder Resolution:	0.0001 deg.
Tracking Velocity:	15 deg/sec(Az) 5 deg/sec(El)
Tracking Accuracy:	1 arc-sec.

Table 2 Performance of the CCD Camera

CCD (GEC Hirst Research Lab., England, P8600 device)		
Type:	Three Phase CCD, Frame Transfer	
Chip Size:	385x578 pixels(8.5x12.7mm)	
Pixel Size:	22x22 μm^2 each	
Performance		
Response Wavelength:	0.38~0.92 μm(λc=0.75 μm)	
Operational Temperature:	140 K	
Peak Quantum Efficiency:	0.6	
Readout Noise(r.m.s):	7.8 $\pm$0.6e	
Output Node Capacitance:	0.124 $\pm$0.011pF	
Dynamic Range:	3×10^5	
Filters	V band:	0.498 —0.591 μm
	R band:	0.630 ~0.762 μm
	I band:	0.820 ~1.15 μm
Field Of View	Nominal:	84'.7x97'.2
	Enlarged:	256"x384"

2. Results of satellite observation

The first tracking experiment for geostationary satellites began in 1989. CS-2a and CS-2b were tracked. Figure 1 shows the relative comparison between the tracking data shown by the open circle, and the calculated value from a NASDA orbital element, shown by the solid line with a time marker of 10 minutes each. The resultant tracking error was 0.001 degrees. Table 3 summarizes the results of the optical tracking experiment for several domestic geostationary satellites. The brightest of them was JCSAT-2. For the darker satellites, such as CS-3b, the S/N ratio could be improved by using the narrow band filter.

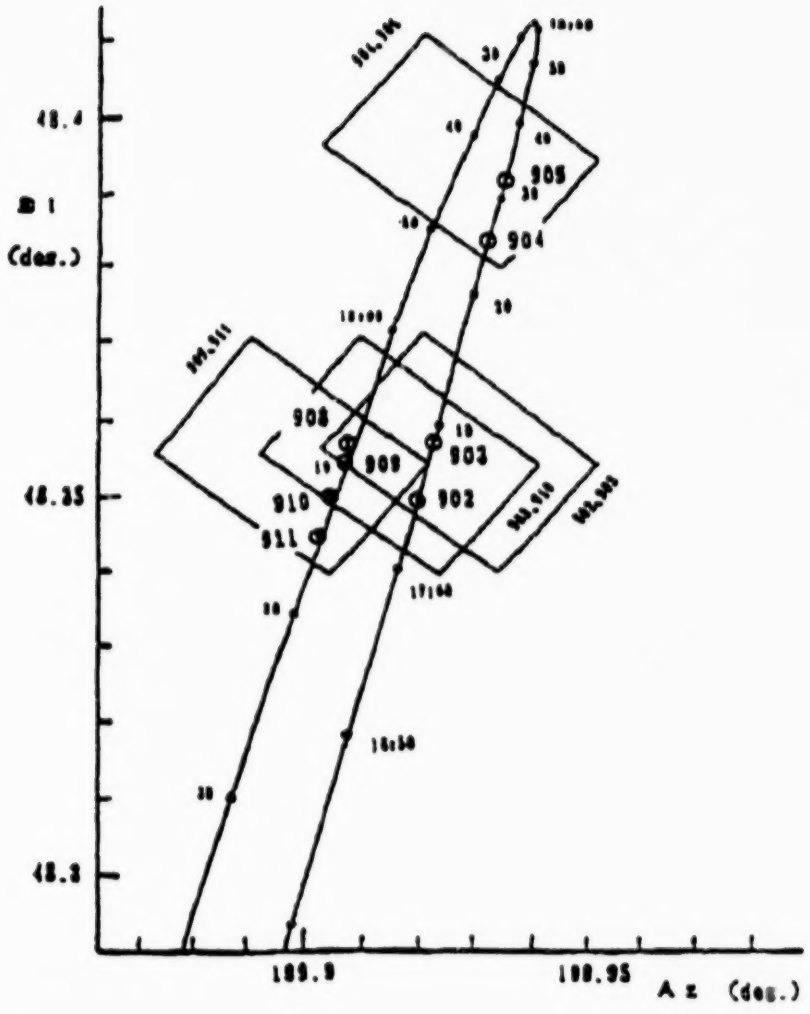

Figure 1 Relative Comparison between the Optical Tracking and Orbital Prediction

Table 3 Summary of the Geostationary Satellite Tracking

Sat. Name	Longitude deg.	Exposure sec.	Read-Out Count	Mag.
CS-2a		5	1.01×10^{5}	13.8
CS-2a		5	7.64×10^{4}	14.1
ETS-V	150.0	5	2.39×10^{5}	12.2
CS-3b	136.0	10	1.64×10^{5}	13.4
CS-3b	136.0	1	2.24×10^{4}	13.0
CS-3b	136.0	10	0.80×10^{5}	14.1
BS-2b	110.0	10	1.54×10^{6}	10.9
JCSAT-1	150.0	10	5.53×10^{6}	9.5
JCSAT-2	154.0	10	6.40×10^{6}	9.4
CS-3a	132 0	10	8.62×10^{5}	11.6
CS-3b	136.0	10	9.27×10^{5}	11.5
CS-3a	132.0	100*	5.00×10^{6}	12.2
CS-3b	136.0	100*	1.90×10^{6}	13.2
BS-2b	110.0	100*	2.01×10^{6}	13.1
JCSAT-2	154.0	100*	4.71×10^{6}	12.2
JCSAT-1	150.0	100*	4.26×10^{6}	12.3

3. Conclusion

It turned out to be quite easy to track geostationary satellites using the CCD imaging system whenever the sky was clear at night. The limiting magnitude of the telescope system was estimated to be about 19^m at a 10-second integration time by observing Japanese domestic geostationary satellites. The system will be effectively used to survey geostationary orbiting objects, such as operational/retired satellites and debris.

References

Y. Arimoto et al., Optical Tracking of Geostationary Satellites using 1.5 m Telescope System with Low-Noise CCD Camera. Proceedings of the 17th International Symposium on Space Technology and Science, Tokyo, 1990.

NORWAY

[Original: English]

Norway has not done any research on space debris.

POLAND

[Original: English]

Research in Poland concerning space debris is of an exploratory character and is a part of broader investigations connected with the space environment and with maintaining outer space for common, peaceful uses.

One of the results of these studies was a working paper submitted by Poland to the thirty-fourth session of the Committee on the Peaceful Uses of Outer Space, held at Graz, Austria, in May-June 1991, proposing the elaboration of a report on the protection and preservation of the outer space environment, especially activities potentially affecting the Earth environment (A/AC.105/L.190).

SWEDEN

[Original: English]

Sweden does not carry out any national research on space debris. Through the Swedish National Space Board support is given to the activities in this field within the European Space Agency (ESA).

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

[Original: English]

SPACE DEBRIS STUDIES WITHIN THE UNITED KINGDOM

Overview

The deleterious space debris environment represents an immediate and increasing hazard to all space operations. The obvious hazard that space debris represents is the collision risk between operational vehicles and debris objects.

The only natural mechanism for the removal of space debris is orbital decay due to the influence of atmospheric drag. Unfortunately this only acts at altitudes up to 1,500 km. The rate of orbital decay increases with higher solar activity, which causes an expansion of the upper atmosphere and thus increased drag on space objects in low Earth orbits. Solar activity reached a

maximum in early 1991, which caused an increase in the re-entry of satellites and debris. However, we will have to wait until the next century for the next peak in activity and subsequent effective removal of debris objects. Active measures for debris control and removal must be sought in the meantime.

The uncontrolled re-entry of large space debris objects such as Salyut 7 and Skylab represents a hazard to the surface of the Earth. This is due to the large in-orbit mass of the vehicles and the small (10 per cent) but significant mass proportion that survives re-entry and impacts the ground. In addition to these highly publicized and infrequent events, the orbits of smaller catalogued objects decay on a daily basis. Further analysis of these frequent events may enable us to gain better insight into the mechanism of natural decay.

Mathematical modelling plays an important role in characterizing the debris environment and providing the link between the catalogued objects and the untrackable population. Traffic models derived from market analysis, break-up (explosion and collision) models derived from laboratory experiments and propagation models accounting for perturbative influences on the motion of the debris objects all help to characterize the current environment and allow prediction of its future evolution and the investigation of debris production and reduction phenomena. The meagre data currently available suggests that the small-particulate artificial population is concentrated in discrete regions in a similar manner to the large object population. This is a departure from the even distribution about near Earth space observed for the natural meteoroid environment and assumed for the debris population in current mathematical models. Such discrepancies may explain why there are many more encounters between space debris objects and operational vehicles than are predicted by the current models.

One of the major sources of debris is the fragmentation of vehicles due to the explosion of propulsion systems or batteries. The redesign of vehicles to enable safe venting of fuel and pressurants and the integration of protective circuits to prevent the explosion of batteries during short circuits should be encouraged. This practice should be mandatory for vehicles in high energy orbits such as the geostationary transfer orbit (GTO) which will continue to intersect LEO for hundreds of years.

In the case of launch vehicle upper stages, appropriate thrusting with a very small propellant budget can reduce the perigee height so that the orbit decays within the atmosphere soon after delivery of its payload. Phasing of the launch window with the lunisolar cycle permits the harnessing of their perturbative influence to reduce the perigee height and orbital lifetime and therefore decreasing the collision probability of the upper stage.

Specification of graveyard orbits (GYOs) above the geostationary ring and provision of adequate fuel budgets to enable boosting at end-of-life should be universally adopted. This will ensure that the Geosynchronous Earth Orbit (GEO), which has no natural mechanism for removing debris objects, will not become overcrowded and a critical spatial density of collision partners

reached. At the most heavily populated longitudes, co-location of satellites and therefore appropriately phased station keeping and operational strategies between agencies should be adopted. The definition of standard manoeuvres for trajectory control is envisaged.

Spacecraft system and subsystem design should evolve to provide adequate redundancy and to ensure that hypervelocity collisions with particulates does not result in failure of the total system and the rendering of the vehicle as an additional piece of debris.

Study programmes and capability within the United Kingdom

Space debris activities within the United Kingdom are focused through the British National Space Centre at the Royal Aerospace Establishment (RAE), DRA Farnborough. Since the beginning of the space age RAE has been compiling the RAE Table of Earth Satellites.[1] This is a catalogue of satellites and associated hardware that are launched into orbit about the Earth. Monthly updates provide information on launch date, orbital lifetime, shape, size and mass of objects and the associated orbital elements determined by US SpaceCom at a particular epoch. The table represents a valuable reference tool for the tracking community and has formed the basis of a number of satellite catalogue databases including the DISCOS[2] database initiated and maintained by the European Space Agency (ESA).

DRA also carries out a re-entry prediction service for risk objects such as the Salyut 7/Kosmos 1686 space station which impacted the surface of the Earth on 7 February 1991. The recent re-entry prediction campaign[3] provided information to both the European Space Agency (ESA)[4] and a number of European States. Research studies are continuing in an attempt to improve re-entry prediction models, but the greatest problems that are encountered are still found to be uncertainties in the behaviour of the atmosphere, lack of vehicle attitude, mass and aerodynamic information. A method[5] pioneered by RAE which does not require such information uses observations of the rate of contraction of the orbit to determine the time of re-entry. This technique does however rely upon frequently updated orbital elements and if, as was the experience with the Salyut 7/Kosmos 1686 re-entry prediction campaign, information is not distributed in a timely fashion to the user community (especially as the time of re-entry approaches) the uncertainty in the predicted re-entry date will remain of the order of 10 per cent of the remaining orbital lifetime.[6]

Debris mitigation strategies have also been explored. The probability of collision in space is dependent upon the number of objects in orbit, the collision cross-section (related to size) of objects, the closing velocity between objects and residence time in orbit of the objects. It is therefore apparent that the massive launch vehicle upper stages which are left in high-energy, highly eccentric orbits following deployment of geostationary satellites will represent a collision hazard to vehicles operating in low-Earth orbit (LEO) for many years following initial orbital injection. The

recent near misses between the STS-48 and STS-49 Space Shuttles and the Soviet launch vehicle upper stages highlight the growing problem. A recent study[7] by RAE explored the strategies available for removing a launch vehicle upper stage from initial injection into geostationary transfer orbit (GTO). Among the techniques considered, which included the use of ballutes (drag augmentation devices) and appropriate choice of launch window to harness lunisolar perturbations to orbit to decrease orbital lifetime, the active propulsive deorbiting of upper stages using either the main propulsive system or a dedicated unit appeared to offer the most effective and practical solution to the problem.

Complementary to these studies, DRA is also designing a particulate detection experiment[8] which will be mounted on a satellite STRV1[9] which it is planned to inject into GTO in late 1993. The detector will provide particulate environment information in a range of orbits from just below GEO down to LEO and will add to the still sparse database on the population derived from Long Duration Exposure Facility (LDEF) studies. Using orbital theory developed at RAE, it is hoped that it will be possible to derive information on the population of 1 mm to 10 cm fragments from observation of the spatio-temporal behaviour of the much smaller particulate population that will be sensed by the detector.[10]

Future studies will seek to construct time-variant models of the population to enable accurate collision probabilities to be calculated for operational vechicles and to determine the effectiveness and impact on the environment of different debris mitigation strategies. LEO constellations will receive attention under this progrmme.

In its role as technical adviser to the United Kingdom Ministry of Defence, DRA defines the altitude of graveyard orbits into which Skynet and North Atlantic Treaty Organization (NATO) satellites will be boosted at the end of their operational life on the geostationary ring. This altitude is currently 500 km above the geostationary ring, in line with ESA policy.

Another United Kingdom centre of research into space debris is the Unit for Space Sciences (UNISPACE) at the University of Kent, Canterbury. The history of measurements of hypervelocity impacts in space began in the early 1960s with the United Kingdom Skylark and Ariel rockets.

UNISPACE experiments have flown on a wide range of United Kingdom and United States rocket and satellite missions measuring the space environment using recoverable techniques (Space Shuttle, LDEF and ESA-Eureca) and in situ electronic detection (Ariel II, Ulysses, Galileo and the Cassini missions). These measurements define the size distribution of particulates, the angular distribution as perceived from a deployed satellite, and using algorithms developed for LDEF, modelling transformations to yield particulate orbital distribution parameters in the geocentric reference frame.

The need to interpret measurements and to develop detection techniques has led UNISPACE to develop an expertise in hypervelocity impact penetration

parameters. The development of a penetration relationship to 16 km/s based on experimental data acquired on a 2MV accelerator exemplifies an achievement in this area (the "Carey McDonnell and Dixon" formula) which relates to supramarginal impacts of micron dimension foils. Also studied (using the 2MV Van der Graaff accelerator) is the time-resolved ionization yield of hypervelocity impact processes and momentum exchange enhancement.

The resident impact facility suite at UNISPACE consists of a 2MV Van der Graaff accelerator capable of providing impacts of up to 90 km/s for micron and sub-micron dimension particulates. This is complemented by a two-stage light gas-gun which provides impacts of larger projectiles to 5 km/s.

UNISPACE has developed the DISCOS database for ESA. This provides real-time interactive facilities to study the characteristics of the currently known orbital population of catalogued objects. UNISPACE is currently involved with SIRA of Kent, United Kingdom, and the Royal Greenwich Observatory, United Kingdom, to study the techniques available to evaluate the space debris environment using ground-based and satellite-based optical techniques.[11] This research is also sponsored by ESA.

Appraisal

The debris population being generated by the current space-faring nations in near-Earth space represents an ominous legacy for the future. The proposed debris mitigation measures for the space environment do not seek to limit in-orbit operations; their purpose is to ensure that space-flight activities will be able to continue unrestricted for future generations. The debris problem can only be resolved by a coordinated effort on the part of the global scientific, technical and legislative community. The United Nations Scientific and Technical Subcommittee would seem the obvious focus for such a programme.

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RAE TABLE OF EARTH SATELLITES
(Year of launch 1991 continued)

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	Name		Launch date, lifetime and descent date	Shape and mass (kg)	Size (m)	Date of orbital determination	Orbital inclination (deg)	Nodal period (min)	Semi major axis (km)	Perigee height (km)	Apogee height (km)	Orbital eccentricity	Argument of perigee (deg)
T L	Cosmos 2139*	1991-25A	1991 Apr 4.45 1 million years	Cylinder + panels + boom 1400	-	1991 Apr 13.8 1991 Apr 21.2	64.81 64.81	667.48 675.74	25300 25508	18698 19111	19145 19149	0.009 0.001	264 232
T L	Cosmos 2140*	1991-25B	1991 Apr 4.45 1 million years	Cylinder + panels + boom 1400	-	1991 Apr 12.4 1991 Apr 20.4	64.81 64.81	674.45 675.74	25476 25508	19039 19105	19156 19154	0.002 0.001	251 247
T L	Cosmos 2141*	1991-25C	1991 Apr 4.45 1 million years	Cylinder + panels + boom 1400	-	1991 Apr 13.8 1991 Apr 28.9	64.82 64.80	684.17 675.73	25720 25508	19147 19108	19536 19151	0.008 0.001	90 316
D	Cosmos 2139 third stage	1991-25D	1991 Apr 4.45 <1 day 1991 Apr 4	Cylinder	6.5 long? 4 dia	1991 Apr 4.5	64.80	87.51	6529	138	164	0.002	316
	Cosmos 2139 fourth stage	1991-25F	1991 Apr 4.45 1 million years	Cylinder 17300 full	5.5 long 4.0 dia	1991 Apr 5.8	64.79	675.53	25503	19109	19140	0.001	312
	Fragments	1991-25E,G											
T?	Anik E2** (Ariane 4-15)	1991-26A	1991 Apr 4.98 >million years	Box + panels 1803	3 x 2.8 x 2.3 23.7 span	1991 Apr 6.6 1991 Apr 10.1 1991 Apr 17.7	0.69 0.25 0.06	917.95 1195.40 1432.76	31291 37313 42101	14078 26119 35692	35748 35751 35754	0.346 0.129 0.001	187 180 116
	Ariane 4-15 third stage	1991-26B	1991 Apr 4.98 500 years	Cylinder 11760 full 1270 empty	9.9 long 2.6 dia	1991 Apr 5.6	4.27	636.71	24532	432	35876	0.722	181

* Glonass payload
** First 5th generation communications satellite for Telesat Canada.